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FREQUENCY-AGILE WIDE-BANDWIDTH POWER INTERFACE TO SUPPORT INCREMENTAL VIRTUAL PROTOTYPING

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14. ABSTRACT
In order to make GaN devices applicable in power electronics and best exploit the capabilities and advantages of these devices, the authors have been involved in the design and fabrication of a novel high-speed, low power-loss driver IC for 1A, 100V GaN HFET devices. The gate driver IC, developed at the University of South Carolina, provides a convenient and smart way to use GaN devices in power electronics, as well as making it possible to achieve miniaturization, high efficiency, reliability, and low cost for power systems. Publications resulting from this work describe the design of the driver IC, demonstrate the effectiveness of the new driver IC and the GaN HFET devices in power electronics applications.

15. SUBJECT TERMS
Wide-bandwidth, power interface, virtual prototyping

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OBJECTIVES

The goal of this project was to develop a wide-bandwidth power converter that could serve as the power interface between a simulation platform and real functioning power hardware. Two technologies were investigated; I) the mathematical basis for correct and stable operation of power hardware in the loop, including experimental verification, and 2) methods for actually implementing the needed very wideband power interface

The first investigation involves development of metrics to evaluate potential interface design solutions. This evaluation in turn informs the design of a Power- Hardware-In-the-Loop (PHIL) experimental platform for applications up to 25 kVA. The second investigation results in the design and implementation of a high-frequency power converter based on GaN HFET power devices (1A, 100V), including a high-speed, low-power-loss integrated circuit gate driver IC.

SUMMARY OF OUTCOMES

Wide Bandwidth Power Interface for PHIL

Background

Current testing procedures for power electronics converters in electric drives usually comprise a costly and time-consuming process especially when the converters have to be connected to electromechanical systems. Hardware-In-the-Loop (HIL) testing is increasingly recognized as an effective approach to simplifying part of this testing process. In Real-Time HIL platforms, simulation models emulate digital and analog signals that interact with the real hardware being tested. However, HIL techniques are mainly confined to tests on the control section (i.e. electronic boards) since only a signal coupling between the real hardware and the virtual system is provided. A natural extension of the concepts of HIL leads to Power- Hardware-In-the-Loop simulations in which natural couplings (nodes involving the conservation of energy) are established and a significant amount of energy can be virtually exchanged between the simulation software and the hardware being tested [2]. Thus, in a PHIL platform test, power devices, such as electrical machines or loads, can be replaced with their simulated counterparts.

Accomplishments

In [I1] a PHIL platform specifically designed to emulate the behavior of an electrical machine in order to perform verification tests on power electronic converters is presented. In [9] we focused on a critical review of the previous experience by pointing out the main deficiencies of the earlier platform and possible upgrades aiming to extend bandwidth, reliability and ease of operations. In [I] an evaluation of two interface design solutions for power hardware-in-the-loop experiments is presented. The evaluation is performed using four figures of merit that focus on both the dynamic and steady-state performances of the interface systems. An analytical process is then used to both compare the different interfaces and, more importantly, to define a design procedure based on an optimization problem. The primary advantage of the proposed approach is that the figures of merits can be calculated by accounting not only for the topology of the interface but also for the structure and characteristics of the controller adopted for the interface itself. In [I2][I3] and [5] we present the design and the realization of a flexible hardware interface to perform PHIL testing up to 25 kVA. See the full papers for complete details.

GaN Power Converter

Background

For a high-fidelity PHIL interface requires much wider bandwidth than would be required of a converter working at the "design" frequency of, say, 60 Hz new high speed power switches are essential. GaN technology promises to meet the requirements. Rapid development of wide-band III-Nitride semiconductor materials (such as GaN) has been driven by the unique properties of these materials, such as high electron mobility, high saturation velocity, high sheet-carrier concentration at hetero-junction interfaces, and high breakdown voltages. These properties make the use of III-Nitride technology a promising approach for high-power, high temperature and high-speed applications in power electronics. These devices can be extremely useful in industrial power electronic applications and can improve the efficiency and the regulation in AC-DC and DC-DC converters. Unfortunately, the use of wide-band III-Nitride (GaN) devices is currently limited mainly to telecom and low-power applications. The lack of high-frequency drivers is one of the factors preventing their application to power converters such as are needed for the high-fidelity, wide-bandwidth power interface for PHIL applications.

Accomplishments

In order to make GaN devices applicable in power electronics and best exploit the capabilities and advantages of these devices, the authors have designed and fabricated a novel high-speed, low-power-loss driver IC for 1A, 100V GaN HFET devices. The gate driver IC, developed at the University of South Carolina, provides a convenient and smart way to use GaN devices in power electronics, as well as making it possible to achieve miniaturization, high efficiency, reliability, and low cost for power systems. The design of the driver IC has been introduced in [7][8][3][10]. In [6], we discussed the effectiveness of the new driver IC and the GaN HFET devices in power electronics applications. The design and the experimental measurements of a high-speed, low power-loss power system, based upon the H-Bridge topology is discussed in [14]. In [4] the improvements in the design and the implementation of the IC are presented. In [14] a full overview is presented. See the full papers for complete details.

PAPERS:

Journal:

1. Santiago Lentijo, Salvatore D'Arco, and Antonello Monti, "Comparing the Dynamic Performances of Power Hardware-in-the-Loop Interfaces" IEEE Transactions On Industrial Electronics, VOL. 57, NO. 4, APRIL 2010

2. Alain Bouscayrol, Antonello Monti, Michael Steurer, "Guest Editorial", IEEE Transactions On Industrial Electronics, vol. 57, no. 4, April 2010

3. Bo Wang, Naveen Tipirneni, Marco Riva, Antonello Monti, Grigory Simin and Enrico Santi, "An Efficient High-Frequency Drive Circuit for GaN Power HFETs" IEEE Transactions On Industry Applications, VOL. 45, NO. 2, MARCH/APRIL 2009

4. Bo Wang, Marco Riva, Jason D. Bakos, Antonello Monti "Integrated Circuit Implementation for a GaN HFET Driver Circuit" IEEE Transactions On Industry Applications, VOL. 46, NO. 5, September/October 2010

Conference:

5. A. Benigni, A. Helmedag, A.M.E. Abdalrahman, G. Piłatowicz and A. Monti "FlePS: a Power Interface for Power Hardware In The Loop" EPE'11 ECCE Europe Power Electronics and Adjustable Speed Drives 30 August to 1 September 2011, Birmingham UK.

6. B. Wang, A. Monti, M. Riva "A High-Speed H-Bridge Circuit Based on GaN HFETs and custom resonant gate drivers" IEEE Energy Conversion Congress and Exposition, 2009. ECCE 2009. Page(s): 973 – 978

7. B. Wang, M. Riva, J. Bakos, A. Monti, "Integrated Circuit Implementation for a GaN HFETs Driver Circuit", in Proc. 2008 Applied Power Electronic Conference (APEC), pp. 901 – 906

8. B.Wang, N. Tipirneni, M.Riva, A.Monti, G.Simin, E. Santi, "A Resonant Drive Circuit for GaN Power MOSHFET" in Proc. 2006 IEEE Industry Application Conference , pp. 364 - 368

9. A. Monti, S. D'Arco, A. Deshmukh, "A New Architecture for Low Cost Power Hardware in the Loop Testing of Power Electronics Equipments" IEEE International Symposium on Industrial Electronics, 2008. ISIE 2008. Page(s): 2183 – 2188

10. N. Tipirneni, B. Wang, A. Monti and G. Simin "AlGaN/GaN Bidirectional Power Switch" 65th Annual Device Research Conference, 2007. Page(s): 97 – 98

11. A. Monti, S. D'Arco, Y. Work, A. Lentini "A Virtual Testing Facility for Elevator and Escalator Systems" IEEE Power Electronics Specialists Conference, 2007. PESC 2007. Page(s): 820 – 825

Thesis/dissertation:

Masters Theses:

12. Grzegorz Piłatowicz "Control Design for a High Frequency Power Hardware-In-The-Loop Interface." (2010). Theses and Dissertations. RWTH Aachen University. Paper 98.

13. Adil M.E. Abdalrahman "Sizing of a Power Electronic Converter for Power Hardware-in-the-Loop Simulation." (2010). RWTH Aachen University. Paper 83.

Phd Dissertations

14.   Wang, Bo, "Wide Bandwidth Control Electronics for GAN-Based Pebbs" (2009). Theses and Dissertations. University of South Carolina. Paper 106. http://scholarcommons.sc.edu/etd/106

Publications

Publications or Reports (May 2011 – August 2011).

Journals: 1

Book or Chapters: none

Technical Reports / Presentations: 1

Workshops: none

Inventions: none

Honors and Invitations: none

Personnel Statistics: (May 2011 – August 2011)

Total Number of Co-PIs: 0

Number of Woman Co-PIs: 0

Number of Minority Co-PIs 0

Total No of research faculty working on the grant: 0

Number of Woman Co-PIs: 0

Number of Minority Co-PIs 0

Total No of students working on the grant: 4

Number of Graduate Students: 1

Number of Woman Grad Students: 0

Number of Minority Grad Students: 0

Number of Under Graduate Students: 3

Number of Woman Under Grad Students: 1

Number of Minority Under Grad Students 0

Total Post Docs: 1

Number of Woman Post Docs: 0

Number of Minority Post Docs 0

No of degrees Granted during this report Period: 1

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